Marine Research

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Marine Research
1959 No. 1

Hydrography of the North-Western Approaches to the British Isles

By D. S. TULLOCH, B.Sc., and J. B. TAIT, D.Sc., Ph.D., F.R.S.E.

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Hydrography of the North-Western Approaches to the British Isles

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Marine Laboratory, Aberdeen

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1959

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Hydrography of the North-Western Approaches to the British Isles

INTRODUCTION

The cruise of the research vessel "SCOTIA" to the region west of Scotland and Ireland in June 1951 was designed to throw light on the question of the immediate origin of the "oceanic" waters entering the Faroe-Shetland Channel over its threshold, the Wyville Thomson Ridge.

Nansen (1913) directly linked the Atlantic Current through the Faroe-Shetland Channel with the "Irish Current" (Krummel, 1911) through the Rockall Channel, but recent evidence, biological and hydrographical, throws at least some doubt on that conception. Fraser (1950, 1952, 1955) for instance, from the study of plankton "indicator" species, suggests the existence of two more or less distinct oceanic "streams" in the Channel, which he designates, respectively, the Lusitanian stream, entering the Channel on its south side along the Continental Edge, and the Atlantic stream, penetrating the north side of the Channel from the open Atlantic to the west. Hydrographic evidence in support of this suggestion is contained in the not infrequent occurrence of two distinct high salinity cores on a vertical section between Faroe and Shetland.

By his hypothesis of cascading and overturn of the upper waters of the Rockall region towards the south-east, Cooper (1952) has also occasioned some doubt as to the immediate southerly origin of the main Faroe-Shetland oceanic stream, notwithstanding that at least occasional hydrographical (also biological) evidence conclusively defines Mediterranean (or Gulf of Gibraltar) water admixture in this stream. It must also be said, however, that hydrographic observations often do indicate the open Atlantic to the west, rather than the Rockall area, as the region whence the Atlantic water in the Channel immediately and directly derives.

Helland-Hansen and Nansen's (1926) earlier interpretation of numerous observations, over a number of years, in the open Atlantic Ocean west and south of the region of the present investigation, as well as the results from the American "CARNEGIE" cruise in the same region in 1928, as reported by Sverdrup (1944), appear to leave open the question of whether the Faroe-Shetland Channel derives its oceanic influence directly from the west or from the south, or indeed from both.

The "SCOTIA" cruise of June 1951 was planned therefore to investigate this question in some detail. Excellent weather conditions were experienced throughout the cruise from the 16th June to 1st July. The positions occupied are shown on Figure 1. They fall into seven linear sections traversing the main bathy-metric features of the region from the Wyville Thomson Ridge in the north, and over the several sea mounts,[1] knolls, and banks, to Porcupine Bank in about latitude 53°30′N, in the South.

INSTRUMENTS AND METHODS

The Pettersson-Nansen insulating water-bottle was used to sample the uppermost 150-200 metres of water. For greater depths, Knudsen reversing bottles of the frameless type were employed in series of six to eight bottles according to circumstances. Each bottle carried a pair of protected reversing thermometers, and each series of bottles two unprotected thermometers, one on the lowest bottle and the other near the top of the series. Operations were conducted simultaneously from two hydrographic davits, thus minimising the time spent at each hydrographic station.

[1]Submarine topographical designations have been adopted which are in accordance with the recommendations of the British National Sub-Committee on the Nomenclature of Ocean Bottom Features.

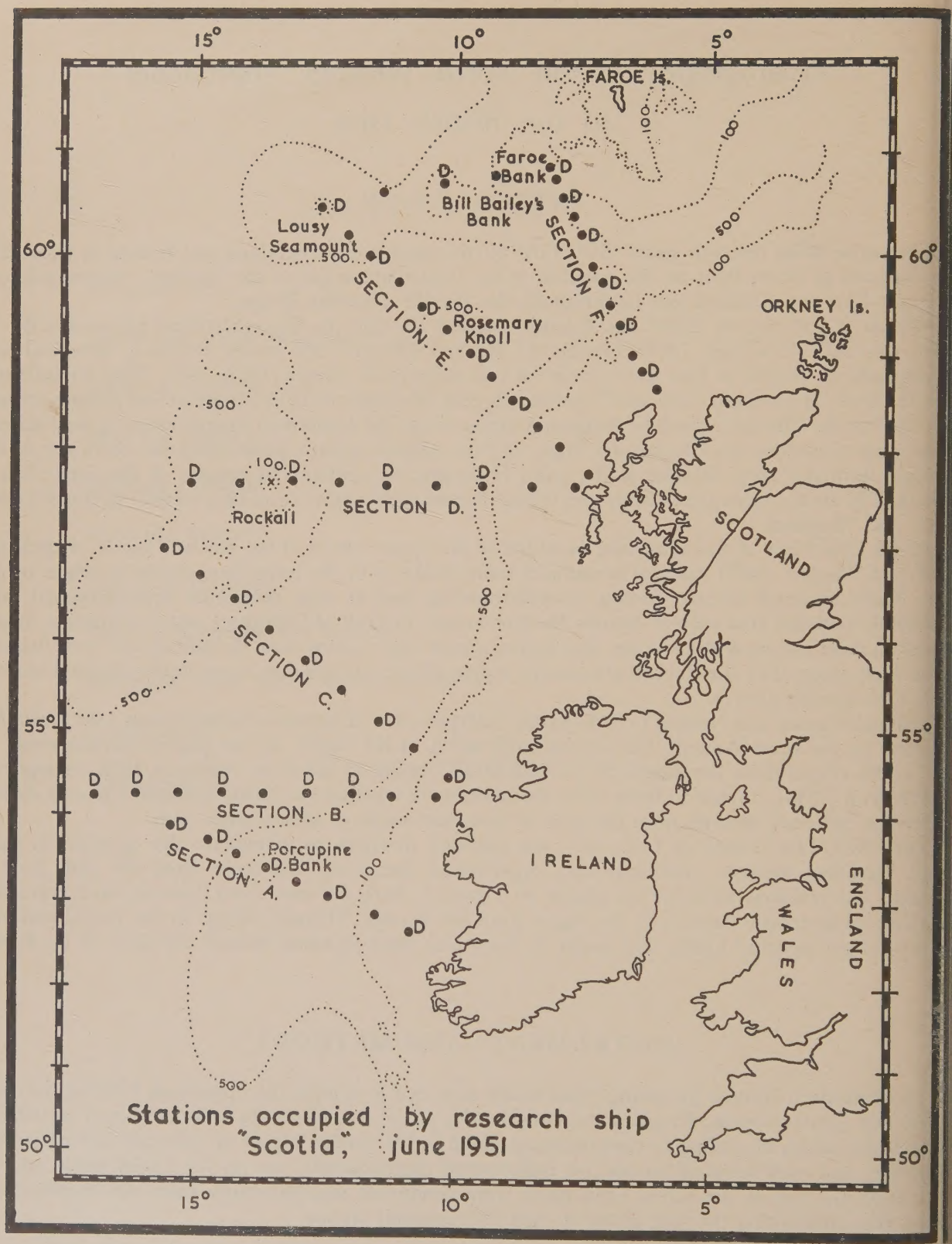

15°
10°
5°
60°
55°
50°
FAROE Is.
Faroe Bank
Bill Bailey's Bank
Lousy Seamount
SECTION E.
SECTION F.
Rosemary Knoll
ORKNEY Is.
SCOTLAND
Rockall
SECTION D.
SECTION C.
SECTION B.
SECTION A.
Porcupine Bank
IRELAND
WALES
ENGLAND
100
500
Stations occupied by research ship "Scotia," june 1951

Fig. 1.

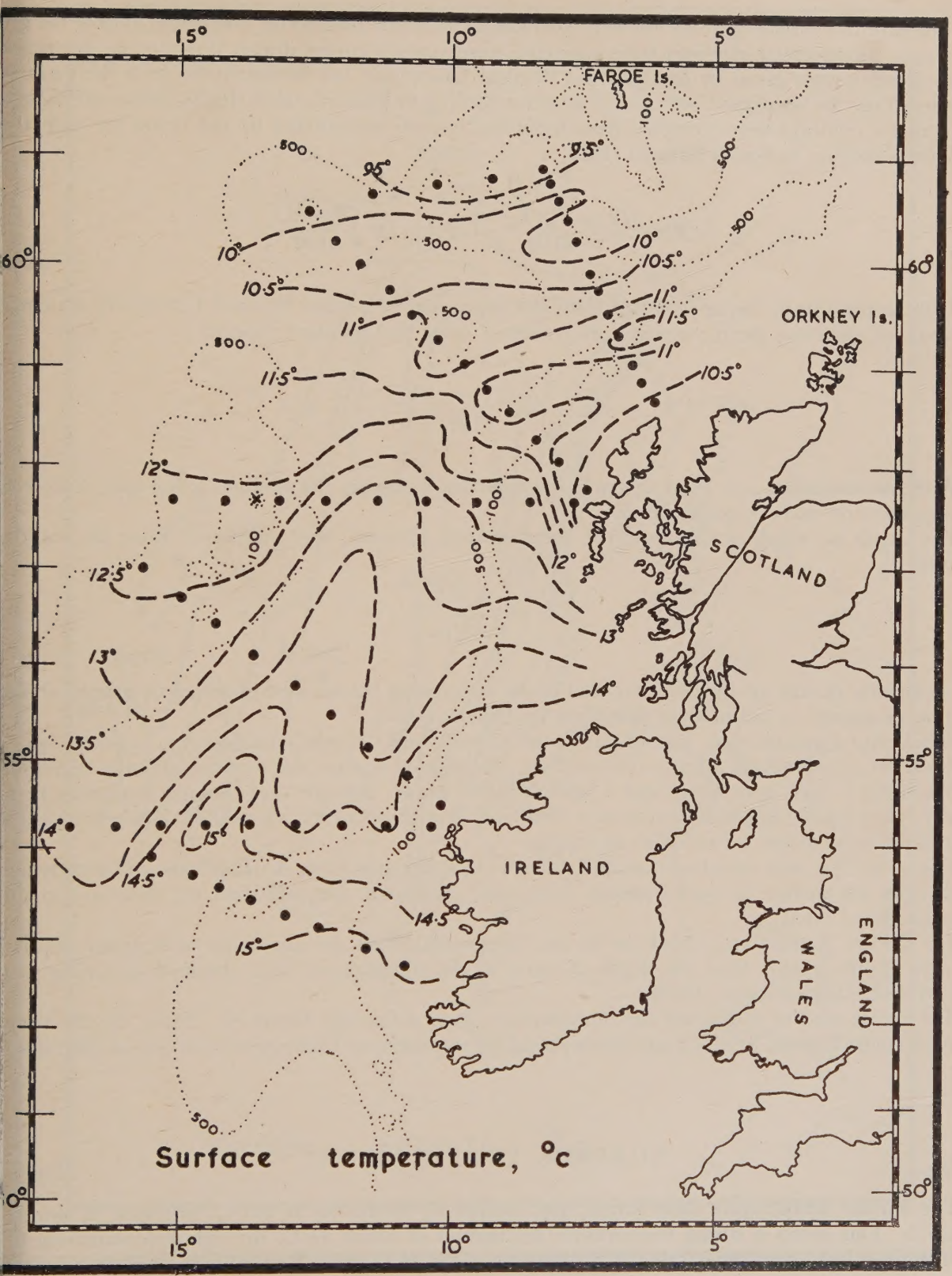

15°
10°
5°
FAROE Is.
ORKNEY Is.
SCOTLAND
IRELAND
WALES
ENGLAND
60°
55°
50°
9·5°
10°
10·5°
11°
11·5°
12°
12·5°
13°
13·5°
14°
14·5°
15°
500
100
Surface temperature, °c

Fig. 2.

Groups of five surface drift-bottles were liberated at alternate stations on the several lines of the grid

Nansen thermometer readings were corrected from smooth curves drawn through the determined points of index error given by the National Physical Laboratory test statement for each thermometer and corrections for adiabatic cooling were added according to Ekman's table (1905). Protected reversing thermometer readings were corrected from individual graphs constructed by the writer for each thermometer according to Sund's formula (1926):

$$\triangle T_p = \left\{ \frac{(T_p+V_o)(T_p-t)}{6100} + I \right\} \left\{ 1 + \frac{(T_p+V_o)}{6100} \right\}$$

the index error I again being obtained from the appropriate National Physical Laboratory statement. Unprotected reversing thermometers were corrected using the standard formula:

$$\triangle T_u = \frac{(T_u+V_o)\ \{(T_p+\triangle T_p) - t\}}{6100} + I$$

With few exceptions very good agreement was obtained between the readings of the pair of protected thermometers on each reversing bottle.

The depth at which the unprotected thermometers reversed were calculated from the standard formula:

$$D = \frac{T_u - T_p}{Q \cdot \rho_m}$$

and from these depths the depths of reversal of the intervening bottles were obtained by graphical interpolation according to the method described by Pollack (1950).

All salinity titrations were carried out at the Government Chemist's Laboratory, London.

Serial temperature and salinity observations were plotted against the thermometrically determined depths, using a very open scale, and a smooth curve drawn through these points. Temperature and salinity values for the standard depths were then read from these curves. Vertical sections of temperature and salinity were drawn for each line of stations.

The quantity σ_t was calculated using O. Sund's Oceanographic Slide Rule, and anomalies of dynamic depth from the surface to each standard level were computed and tabulated for each station using Lafond's tables (1951).

For shallow stations on a bank or on the Continental Shelf the anomalies of dynamic depth for standard depths greater than the depth of water at the station have been obtained according to the method of Helland-Hansen (1934).

The charts used in this paper are reproductions from Admiralty Chart No. 2060a, North Atlantic Ocean-Eastern Portion, to which have been added the approximate bathymetric contours of 500 fathoms.

SURFACE TEMPERATURE

The surface temperature distribution, represented by isotherms at 0.5°C. intervals, is shown in Figure 2. This shows a strong temperature declination of about 5½°C. through approximately 8° of latitude, from 15°C. near the parallel of Shannon (*ca.* 52°30′N.) to 9·5°C. near Faroe Bank (*ca.* 60°30′N.). It is evident that a tongue of warm water projected north-northeastwards into the region between Rockall Tablemount and the Continental Shelf, apparently deriving from still further south than the

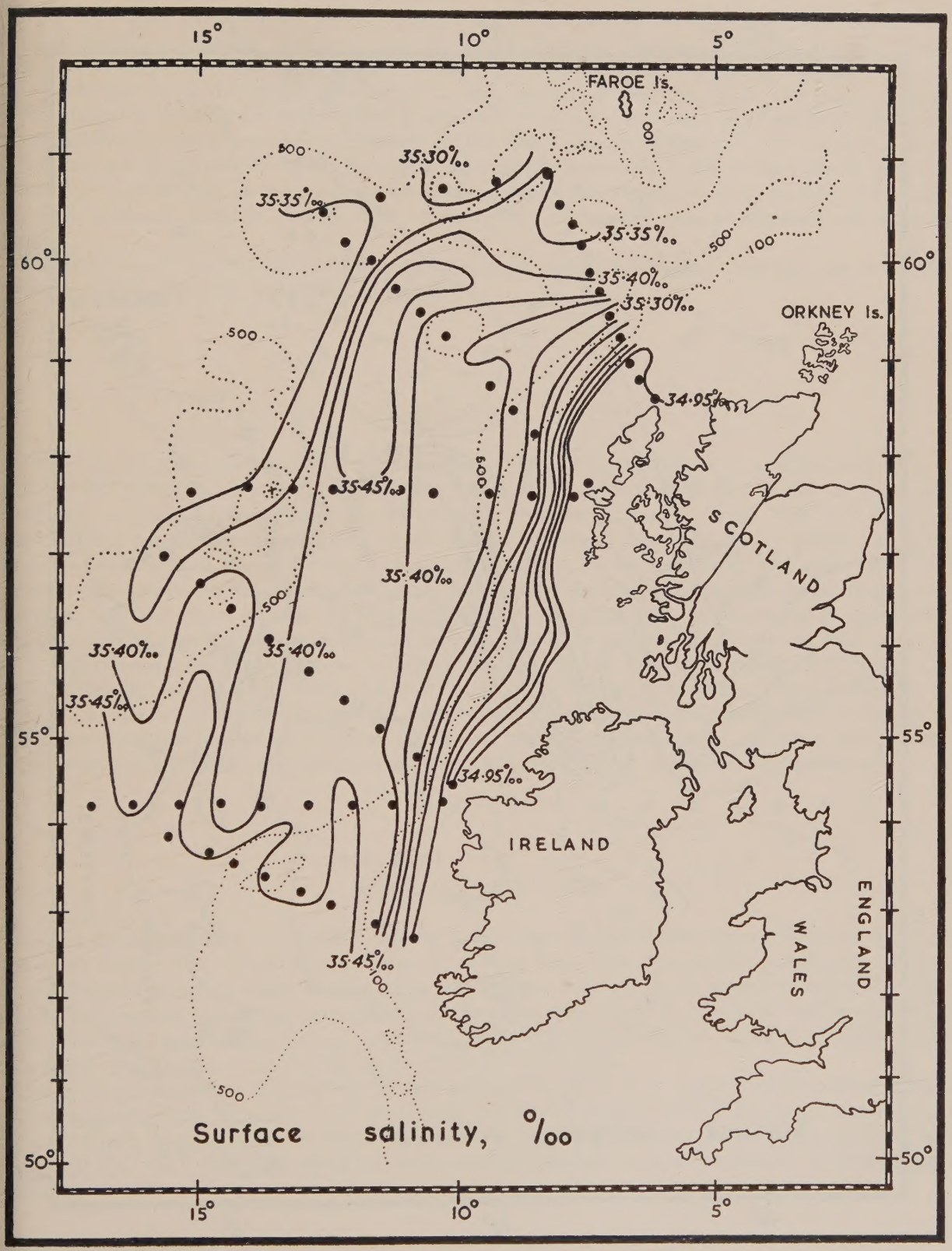

15°
10°
5°
FAROE Is.
100
500
35·30‰
35·35‰
35·35‰
35·40‰
35·30‰
ORKNEY Is.
60°
500
34·95‰
35·45‰
500
SCOTLAND
35·40‰
35·40‰
35·40‰
35·45‰
55°
34·95‰
IRELAND
ENGLAND
WALES
35·45‰
100
500
Surface salinity, ‰
50°
15°
10°
5°

Fig. 3.

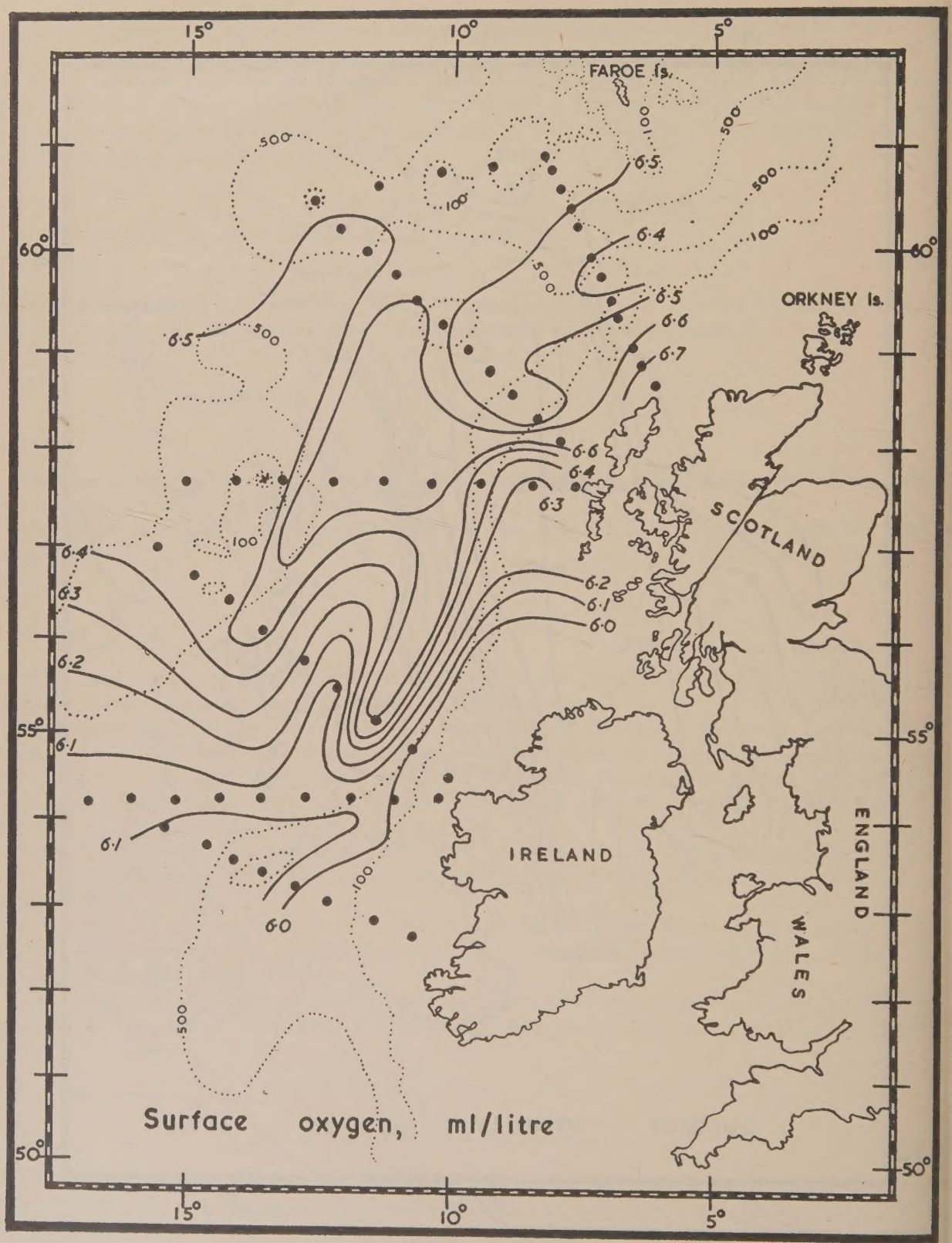

15°
10°
5°
FAROE Is.
ORKNEY Is.
SCOTLAND
IRELAND
ENGLAND
WALES
60°
55°
50°
500
100
6·5
6·4
6·6
6·7
6·3
6·2
6·1
6·0
Surface oxygen, ml/litre

Fig. 4.

limit of the region investigated. Between Rosemary Knoll and Faroe Bank this N.E. flow evidently changed direction abruptly eastward into the Faroe-Shetland Channel over the Wyville Thomson Ridge. It seems at the same time to have become more restricted by reactionary influences on either side. Colder water, to the extent of about 2°C., and emanating from the north, was present along the line of submarine elevations from Faroe Bank westward to Lousy Seamount, and a barrier to this southerly directed influence was apparently constituted by the direct passage of oceanic water eastward from the open ocean into the Faroe-Shetland Channel between Lousy Seamount and Rosemary Knoll, converging, in the latter neighbourhood, with the current from the south. On the other, southern side of this current, restrictive influence probably derived from coastal waters of the west coast of Scotland and its outlying islands.

The influence of the Rockall Tablemount on oceanic waters proceeding from the west is evident in the trend of the isotherms southward of Rockall.

SURFACE SALINITY

The surface salinity distribution is represented in Figure 3 by isohalines at intervals of 0·05‰.

The most prominent feature of the distribution is the longitudinal central region of high salinity (35·40‰ to >35·45‰) water, evidently representative of a current from the south. This, as was indicated by the surface temperature distribution, bends sharply eastwards round Rosemary Knoll, and is sandwiched between coastal water of rapidly diminishing salinity on the one hand, and open ocean waters of slightly less salinity on the other, these open ocean waters themselves being subject to a diminution in salinity as they are about to enter the Faroe-Shetland Channel proper, on account of fresher influence from the north along their left flank. In addition, the spacing of the isohalines between Rosemary Knoll and the Continental Shelf would seem to indicate the presence of some more restrictive influence to the northerly flowing current than would appear to be due solely to less saline coastal water influence.

Again, to the south of Rockall, over the tablemount on which the Rock stands, there is indication of a deviation southward of oceanic waters coming in towards this submarine elevation from the west. The possibility of an eddy or swirl about the tablemount cannot of course be discounted.

SURFACE OXYGEN

Oxygen determinations were made only at approximately alternate stations. Nevertheless, as represented in Figure 4 by oxy-isolines at intervals of 0·10 ml.0_2/litre, the surface oxygen distribution in its main features resembles those of the surface temperature and salinity. A tongue of water of relatively lower oxygen content projecting northward into the channel between the Rockall Tablemount and the Continental Shelf lay between oceanic water over Rockall Tablemount of about 6·5 ml/litre oxygen content and coastal waters containing up to about 6·7 ml.0_2/litre.

The same indications as by temperature and salinity are given of (a) oceanic water passing eastward into the Faroe-Shetland Channel on about latitude 60°N., converging with water from the south round Rosemary Knoll, and (b) of the marked reaction to the southerly influence in the region between Rosemary Knoll and the Continental Shelf on which relatively highly oxygenated coastal water influence is apparent.

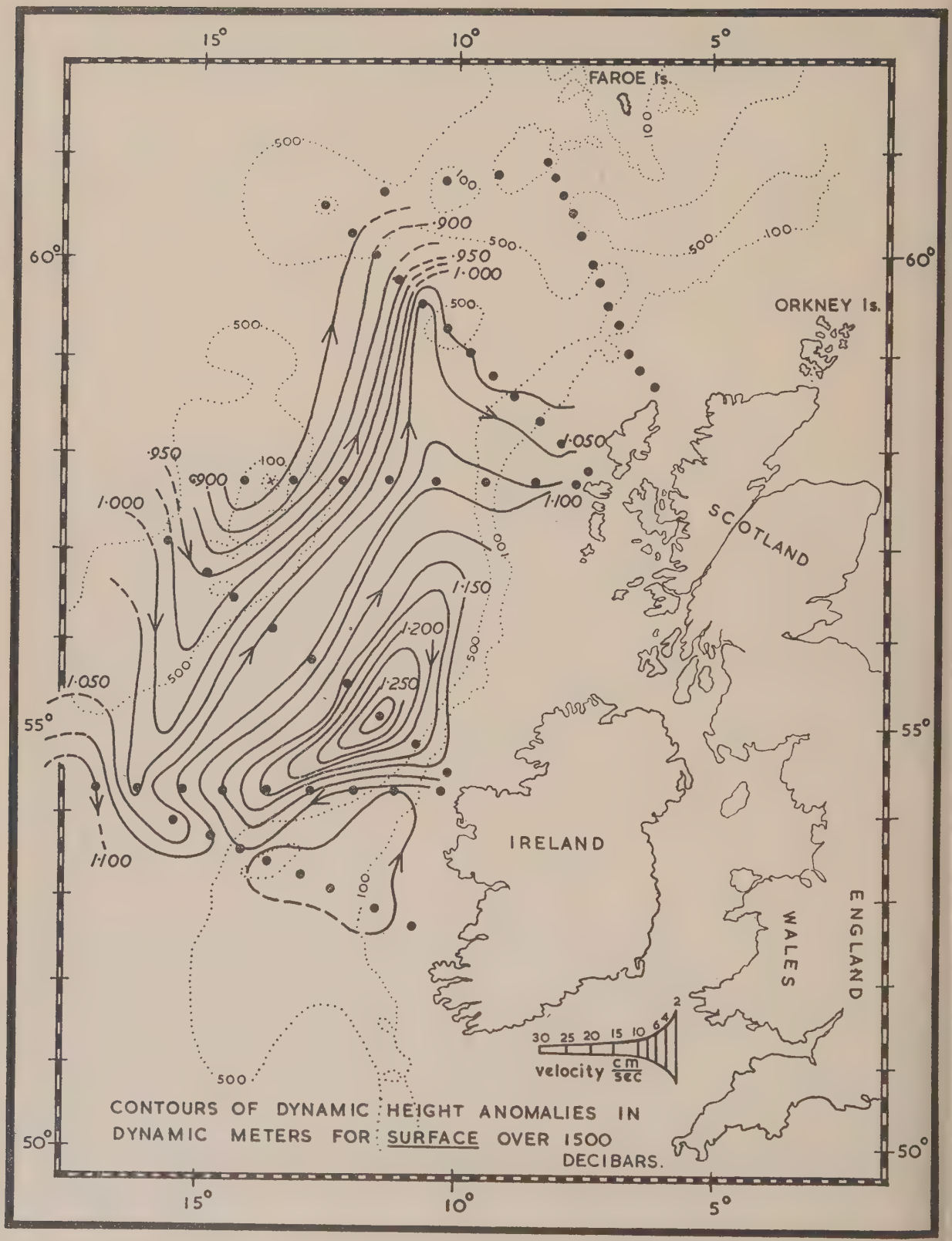

15°
10°
5°
FAROE Is.
ORKNEY Is.
SCOTLAND
IRELAND
WALES
ENGLAND
60°
55°
50°
·500
·100
·900
·950
1·000
1·050
1·100
1·150
1·200
1·250
30 25 20 15 10 6 4 2
velocity cm/sec
CONTOURS OF DYNAMIC HEIGHT ANOMALIES IN DYNAMIC METERS FOR SURFACE OVER 1500 DECIBARS.

Fig. 5.

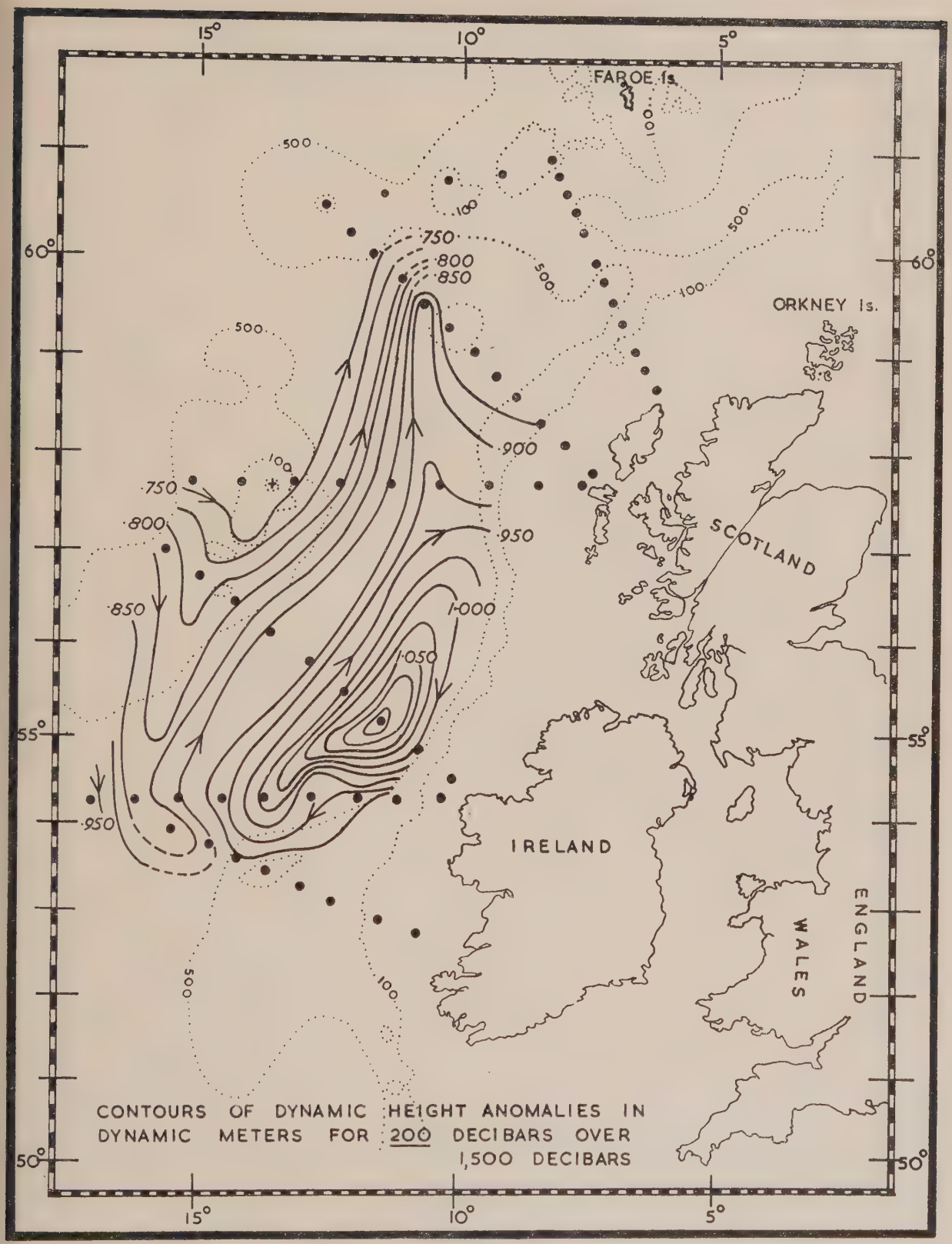

15°
10°
5°
FAROE Is.
60°
ORKNEY Is.
SCOTLAND
55°
IRELAND
WALES
ENGLAND
50°
500
100
750
800
850
900
950
1·000
1·050
CONTOURS OF DYNAMIC HEIGHT ANOMALIES IN DYNAMIC METERS FOR 200 DECIBARS OVER 1,500 DECIBARS

Fig. 6.

15°
10°
5°
FAROE Is.
ORKNEY Is.
SCOTLAND
IRELAND
WALES
ENGLAND
60°
55°
50°
500
600
650
700
750
800
850
900
100
CONTOURS OF DYNAMIC HEIGHT ANOMALIES IN DYNAMIC METERS FOR 400 DECIBARS OVER 1,500 DECIBARS

Fig. 7.

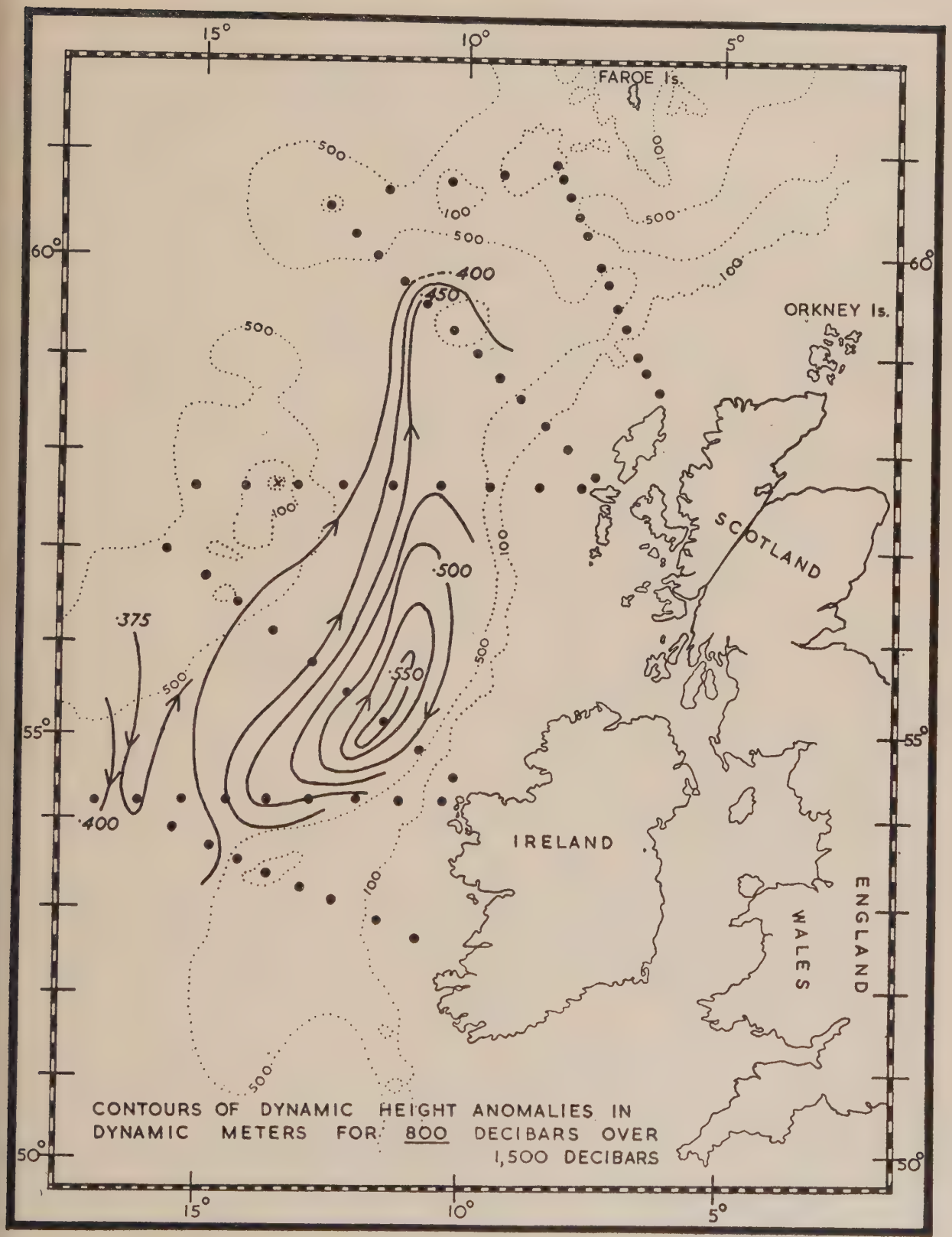

15°
10°
5°
FAROE Is.
60°
ORKNEY Is.
SCOTLAND
55°
IRELAND
ENGLAND
WALES
50°
500
100
400
450
375
550
CONTOURS OF DYNAMIC HEIGHT ANOMALIES IN DYNAMIC METERS FOR 800 DECIBARS OVER 1,500 DECIBARS

Fig. 8.

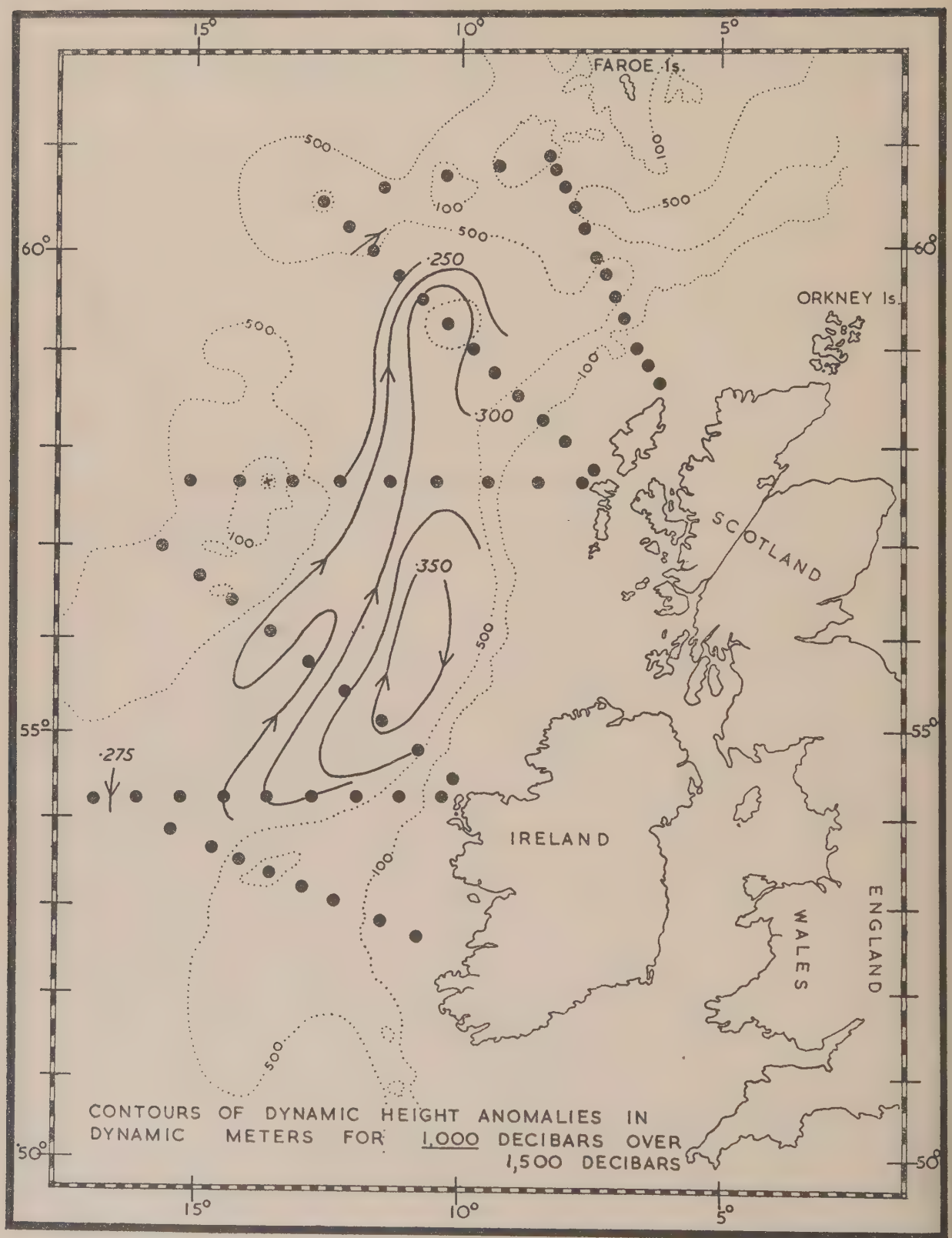

15°
10°
5°
FAROE Is.
ORKNEY Is.
SCOTLAND
IRELAND
WALES
ENGLAND
60°
55°
50°
500
100
250
300
350
275
CONTOURS OF DYNAMIC HEIGHT ANOMALIES IN
DYNAMIC METERS FOR 1,000 DECIBARS OVER
1,500 DECIBARS

Fig. 9.

DYNAMIC RESULTS

The dynamic topographies of the isobaric surfaces 0, 200, 400, 800 and 1,000 decibars relative to the 1,500 decibar surface are shown on Figures 5 to 9 respectively. A second series of these topographical charts based on the 1,800 decibar surface as reference level, showed practically no differences from the series here reproduced.

Bearing in mind the relative nature of these dynamic diagrams the following features are apparent:

1. A wide branch, doubtless of the main North Atlantic Current, evidently swept south-eastwards across Rockall Tablemount, to the south of Rockall itself, and then bent sharply to the north-northeast, flowing strongly in this direction in the western part of the channel between Rockall and the Continental Shelf. Its speed, estimated very approximately from these calculations, was of the order of about 5 miles/day.

   This main current continued in a north-northeasterly direction to the region between the Lousy Seamount and Rosemary Knoll where it evidently turned due east towards the Wyville Thomson Ridge, probably under the combined influence of forces from the west and north.
2. The dynamic diagrams strongly confirm the previous deductions from the surface salinity and oxygen distributions, of the existence of a barrier to the northward progress of waters beyond the region between Rosemary Knoll and the Outer Hebrides. The nature of the barrier is not at once apparent, but in a region of strongly marked bottom topography, the paucity of soundings may well mask features of submarine elevation which might constitute such a barrier.
3. South-east of the main northerly flowing current between Rockall and Ireland, an extensive clockwise circulation, about a central position near 55°07′N 11°29′W., was evident off the north-west Irish coast, in a great bight of the 500 fathoms bathymetric contour.
4. Superficial evidence, at least, points to the existence of a smaller anti-clockwise circulation immediately south of the larger system just mentioned.
5. Immediately south of Rockall Tablemount, pecked lines on Figure 5 suggest a northerly-directed current being diverted towards the south-east by convergence with and under the influence of the current which passes over the tablemount in the latter direction from the open Atlantic Ocean. This indication of southerly derived current towards Rockall Tablemount is given, not by the dynamical, but by plankton evidence from the same cruise which was kindly placed at disposal by Dr. J. H. Fraser. It is further indicated by drift-bottle results, to be cited later, that part of this south-easterly directed current continues in this direction, passing southwards of Ireland with components into the Irish Sea, the English Channel and possibly also into the Bay of Biscay.

From the dynamic topographies of subsurface levels it appears that the directions of the horizontal movements correspond with those at the surface, at least down to 800 metres depth. In the deepest part of the channel between Rockall and the west Irish coast, exceeding 2,000 metres, the waters have the almost uniform characteristics of temperature less than 3°C and salinity less than 34·95‰; planktonic evidence (Fraser, 1955) suggests that this water was drifting southwards, probably at a very slow rate.

VERTICAL SECTIONS

Vertical sections of salinity and temperature distributions are shown on Figures 10 to 15. The isohalines are spaced at 0·05‰ intervals and isotherms at 1°C intervals, these being appropriate to show the main characteristics of the water types present.

On the most southerly section (Section A, Figure 1) two well-defined cores of high salinity (>35·45‰), warm (>10°C) water are delineated (Figure 10), one over and the other just beyond the Continental Shelf. As Cooper and Vaux (1949) and, later Tait (1957) have shown, water in these regions of salinity significantly in excess of 35·45‰ at least begins to be indicative of Gulf of Gibraltar water. The indication is in the present case confirmed by the fact that each of the above cores possesses a high salinity nucleus at

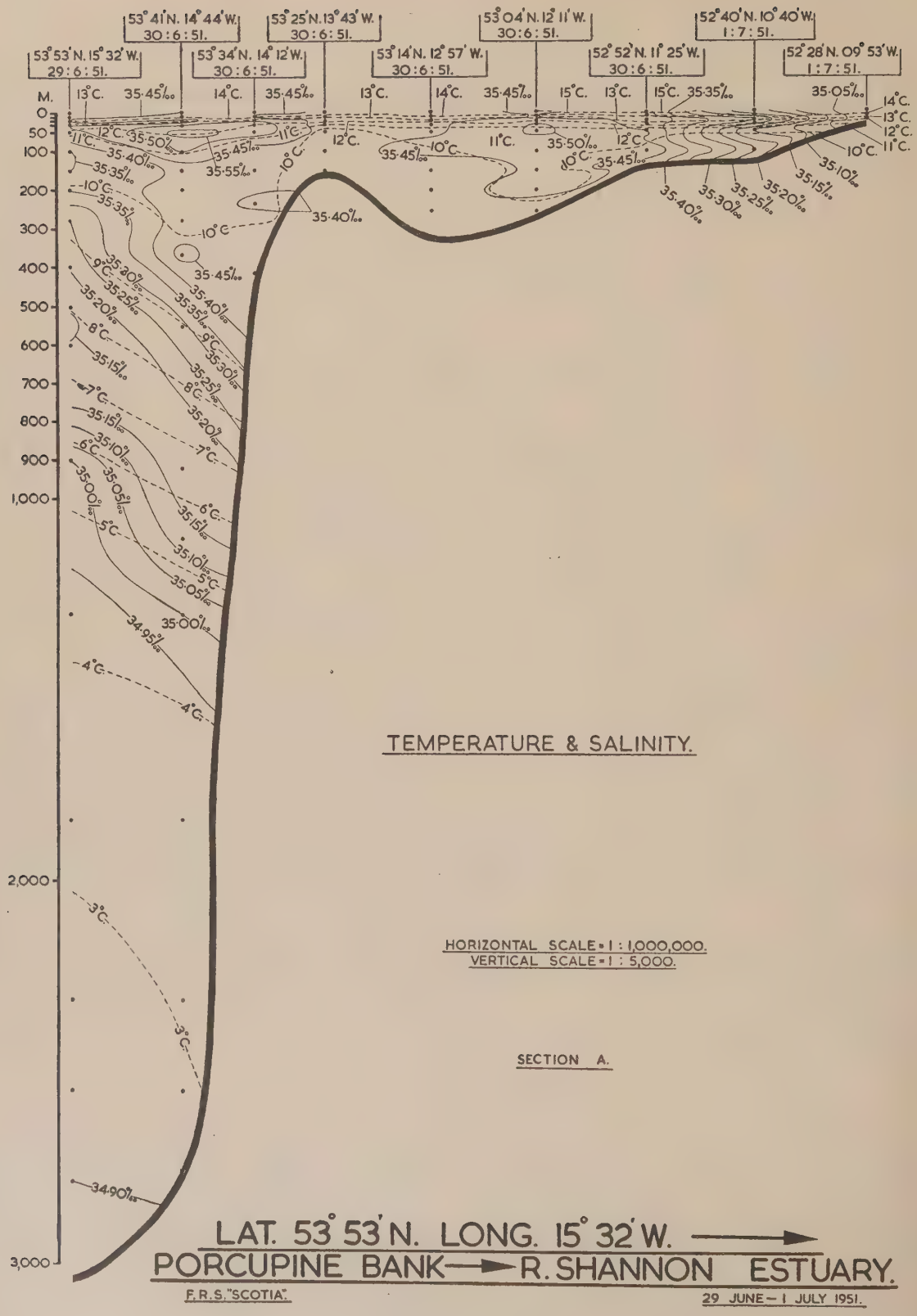

53° 41' N. 14° 44' W.
30 : 6 : 51.
53° 25' N. 13° 43' W.
30 : 6 : 51.
53° 04' N. 12° 11' W.
30 : 6 : 51.
52° 40' N. 10° 40' W.
1 : 7 : 51.
53° 53' N. 15° 32' W.
29 : 6 : 51.
53° 34' N. 14° 12' W.
30 : 6 : 51.
53° 14' N. 12° 57' W.
30 : 6 : 51.
52° 52' N. 11° 25' W.
30 : 6 : 51.
52° 28' N. 09° 53' W.
1 : 7 : 51.
M.
0
50
100
200
300
400
500
600
700
800
900
1,000
2,000
3,000
TEMPERATURE & SALINITY.
HORIZONTAL SCALE = 1 : 1,000,000.
VERTICAL SCALE = 1 : 5,000.
SECTION A.
LAT. 53° 53' N. LONG. 15° 32' W.
PORCUPINE BANK → R. SHANNON ESTUARY.
F.R.S. "SCOTIA".
29 JUNE – 1 JULY 1951.

Fig. 10.

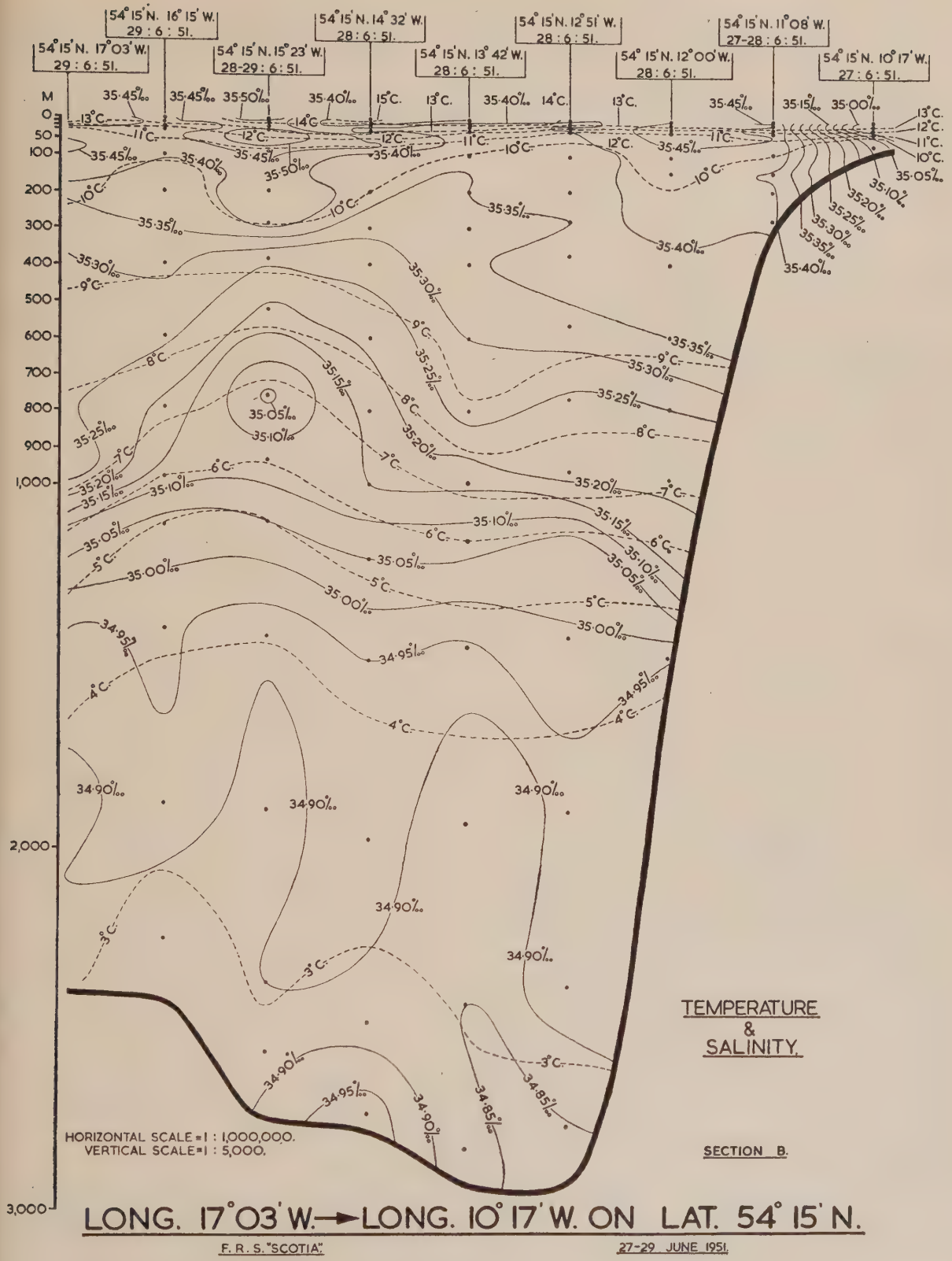

54° 15' N. 17° 03' W. 29 : 6 : 51.
54° 15' N. 16° 15' W. 29 : 6 : 51.
54° 15' N. 15° 23' W. 28-29 : 6 : 51.
54° 15' N. 14° 32' W. 28 : 6 : 51.
54° 15' N. 13° 42' W. 28 : 6 : 51.
54° 15' N. 12° 51' W. 28 : 6 : 51.
54° 15' N. 12° 00' W. 28 : 6 : 51.
54° 15' N. 11° 08' W. 27-28 : 6 : 51.
54° 15' N. 10° 17' W. 27 : 6 : 51.
M
0
50
100
200
300
400
500
600
700
800
900
1,000
2,000
3,000
TEMPERATURE & SALINITY.
HORIZONTAL SCALE = 1 : 1,000,000.
VERTICAL SCALE = 1 : 5,000.
SECTION B.
LONG. 17° 03' W. → LONG. 10° 17' W. ON LAT. 54° 15' N.
F. R. S. "SCOTIA"
27-29 JUNE 1951.

Fig. 11.

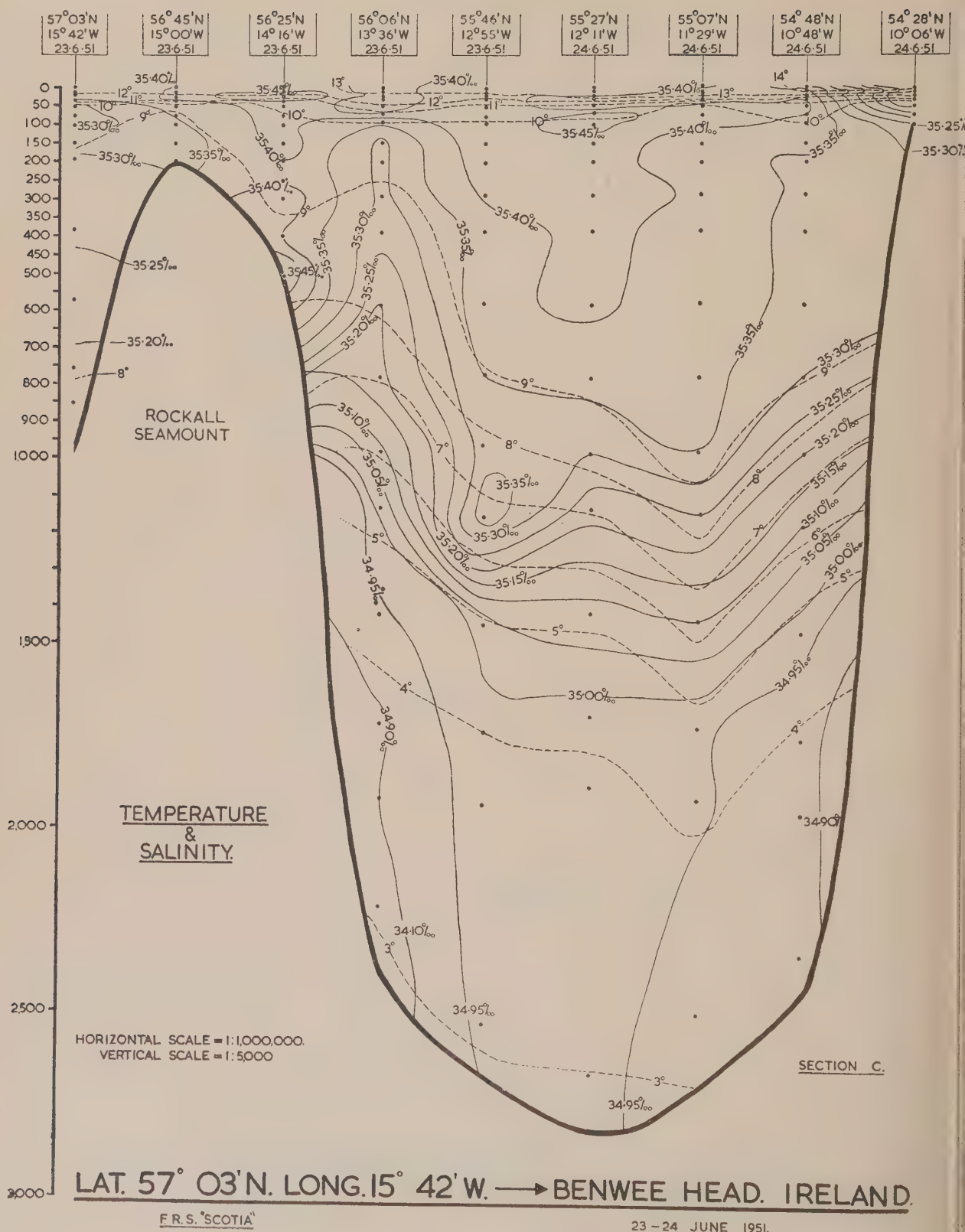

57°03'N 15°42'W 23·6·51
56°45'N 15°00'W 23·6·51
56°25'N 14°16'W 23·6·51
56°06'N 13°36'W 23·6·51
55°46'N 12°55'W 23·6·51
55°27'N 12°11'W 24·6·51
55°07'N 11°29'W 24·6·51
54°48'N 10°48'W 24·6·51
54°28'N 10°06'W 24·6·51
ROCKALL SEAMOUNT
TEMPERATURE & SALINITY.
HORIZONTAL SCALE = 1:1,000,000.
VERTICAL SCALE = 1:5,000
SECTION C.
LAT. 57° 03'N. LONG. 15° 42'W. ⟶ BENWEE HEAD. IRELAND.
F.R.S. "SCOTIA"
23 – 24 JUNE 1951.

Fig. 12.

a common depth of 50 metres, of 35·57‰ in the western core and 35·51‰ in the eastern one. The more westerly core evidently represents a main north-going current, namely that which Fraser (1950, 1955) from plankton evidence, designates the "Lusitanian" stream. The eastern core on Section A occurred apparently about the southern boundary region of the small eddy shown on Figure 5, between Porcupine Bank and the west coast of Ireland, and probably therefore represents something in the nature of a return portion from the eastern border of the main north-going, southerly-derived Lusitanian stream off the Continental Shelf.

As regards temperature, the uppermost waters of Section A show a sharp fall of approximately 4°C within 50 metres from superficial maxima approaching, and at three positions exceeding, 15°C.

The intermediate waters of the deeper part of Section A, from about 200 metres to between 1200 and 1500 metres, show a steady decline in both temperature and salinity, from approximately 10°C to 4°C in the one case and about 35·40‰ to 34·95‰ in the other. The deepest waters of the section to about 3000 metres registered temperatures a little under 3°C and salinities approximating to 34·90‰.

The above-mentioned two cores of southerly derived (probably Gulf of Gibraltar) high salinity water are again in evidence on Section B, Figure 1 (see Figure 11). The cores are still contained within 35·45‰ isohalines, although they may almost equally be regarded as being defined by the 35·40‰ isohalines on Figure 11, thus supporting the inference of dilution of the water-mass on its northward progress from Section A to Section B (Figures 10, 11) which the relative restrictions of the cross-sectional areas contained within the 35·45‰ isohalines seem to indicate. The respective high salinity nuclei show the same feature, by reduction from 35·57‰ to 35·55‰ in the case of the western core, and from 35·51‰ to 35·48‰ on the eastern one, both nuclei, however, again appearing at or about 50 metres depth.

The uppermost 50-100 metre layer of Section B evinces similar sharp temperature declination as on Section A, but from, on the whole, slightly lesser surface maxima of only about 14°C except at a single station where 15·21°C was registered.

The forms of the isotherms and isohalines from the upper through the intermediate water layers on the left of Figure 11, as well as their values, might be interpretated as indicative of intrusion into these layers of a water-mass from the N.E. Atlantic Ocean west of Rockall, this water-mass after overflowing the Rockall Tablemount, sinking below the north-going Lusitanian stream and becoming itself diverted northwards.

The evidence of the deep water isotherms and isohalines on Section B points to considerable turbulence in these waters. The presence in the deepest parts of an apparently irregular watermass in cross-section, with salinity below 34·90‰ to 34·83‰, and temperature around 3°C is worthy of note here. This would appear to be intermediate Arctic water (see Tait, 1957, p. 79) which suggests southerly movement of these deepest waters of the section, in accord with Fraser's (1955) deduction from plankton evidence.

Further attenuation of the north-going Gulf of Gibraltar water current in the western part of the Rockall Channel is implicit in the maximal nuclear salinity of 35·51‰ at 20 metres depth over towards the Rockall Tablemount on Section C. This, it may be recalled, compares with correspondingly occurring maximum nuclear values of 35·57‰ on Section A and 35·55‰ on Section B, both, however, at 50 metres depth. The upward displacement of the nucleus of the core of the current on Section C would appear from Figure 12 to have been due to an intrustion of Atlantic water between about 50 and 200 metres from over the Rockall Tablemount, which had apparently the additional effect of detaching a small part of the Gulf of Gibraltar water-mass and driving it down the eastern slope of the tablemount, for on the bottom, at 500 metres depth, vertically below the above isolated maximal salinity value of 35·51‰ another such value of 35·50‰ was recorded.

Section C also shows an eastern high salinity nucleus within a core of 35·45‰ plus salinity water, corresponding to those illustrated in Figures 10 and 11 in respect of Sections A and B. This core, on Section C, was still more restricted in cross-sectional area, but the nuclear salinity, at 35·48‰, was the same as that recorded on Section B, but, at the greater depth of 75 metres. It is probable that, as indicated by the dynamic topographical chart, Figure 5, and by the arrows on Figure 20 which appear to link the relevant station positions on Sections C and B, these two identical maximal salinity values of 35·48‰ were physically connected in the eddy circulation depicted on these two diagrams evolved from different processes of assessment.

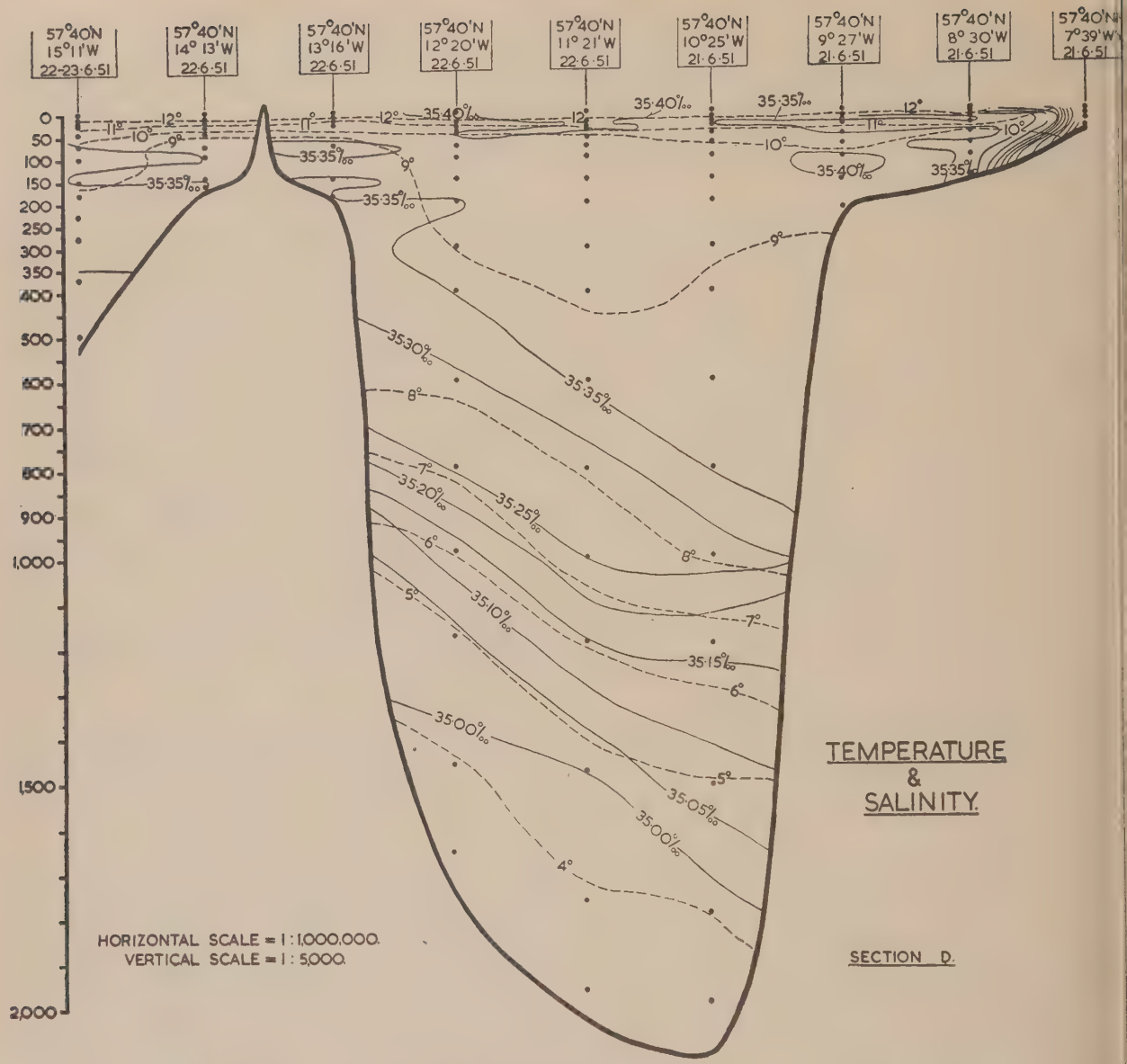

57°40'N 15°11'W 22-23-6-51
57°40'N 14° 13'W 22-6-51
57°40'N 13°16'W 22-6-51
57°40'N 12°20'W 22-6-51
57°40'N 11° 21'W 22-6-51
57°40'N 10°25'W 21-6-51
57°40'N 9° 27'W 21-6-51
57°40'N 8° 30'W 21-6-51
57°40'N 7°39'W 21-6-51
0
50
100
150
200
250
300
350
400
500
600
700
800
900
1,000
1,500
2,000
35·40‰
35·35‰
35·30‰
35·25‰
35·20‰
35·15‰
35·10‰
35·05‰
35·00‰
TEMPERATURE & SALINITY.
HORIZONTAL SCALE = 1 : 1,000,000.
VERTICAL SCALE = 1 : 5,000.
SECTION D.
LONG. 15°11'W. → ROCKALL → S.UIST ON LAT. 57°40'N.
F.R.S. "SCOTIA"
21-23 JUNE 1951

Fig. 13.

There would appear also from Section C, by the salinity distribution in particular, although the 9°C to 6°C isotherms also suggest the process, to have been a fairly strong upwelling movement almost alongside the Rockall Tablemount, reaching almost to within 100 metres of the surface and doubtless at least to some extent conditioned by the divergence of the uppermost waters from the west into the north-going current through the Channel.

Thermal and saline distributions over the remainder of the Section, to nearly 1500 metres depth, seem to be in conformity with the conditions of a large anticyclonic circulation almost diametrically through the centre of which, according to these investigations, Section C apparently passed. The surface layer of the section, within about 100 metres, showed a similarly sharp thermal declination as in the two previous sections, from superficial maxima of approximately 13·5°C (except in the somewhat fresher Irish coastal waters where they exceeded 14°C), to about 10°C.

It seems singular that, after its relatively substantial appearance on Section B, further to the south, only a small cross-sectional area, confined to the lower slope of the Rockall Tablemount, which by its salinity seems representative of intermediate Arctic water and that only just so, should occur on Section C. The remainder of the bottom waters of this section with salinity in excess of 34·90‰ thus signify origin from the deep water-mass of the Norwegian Sea.

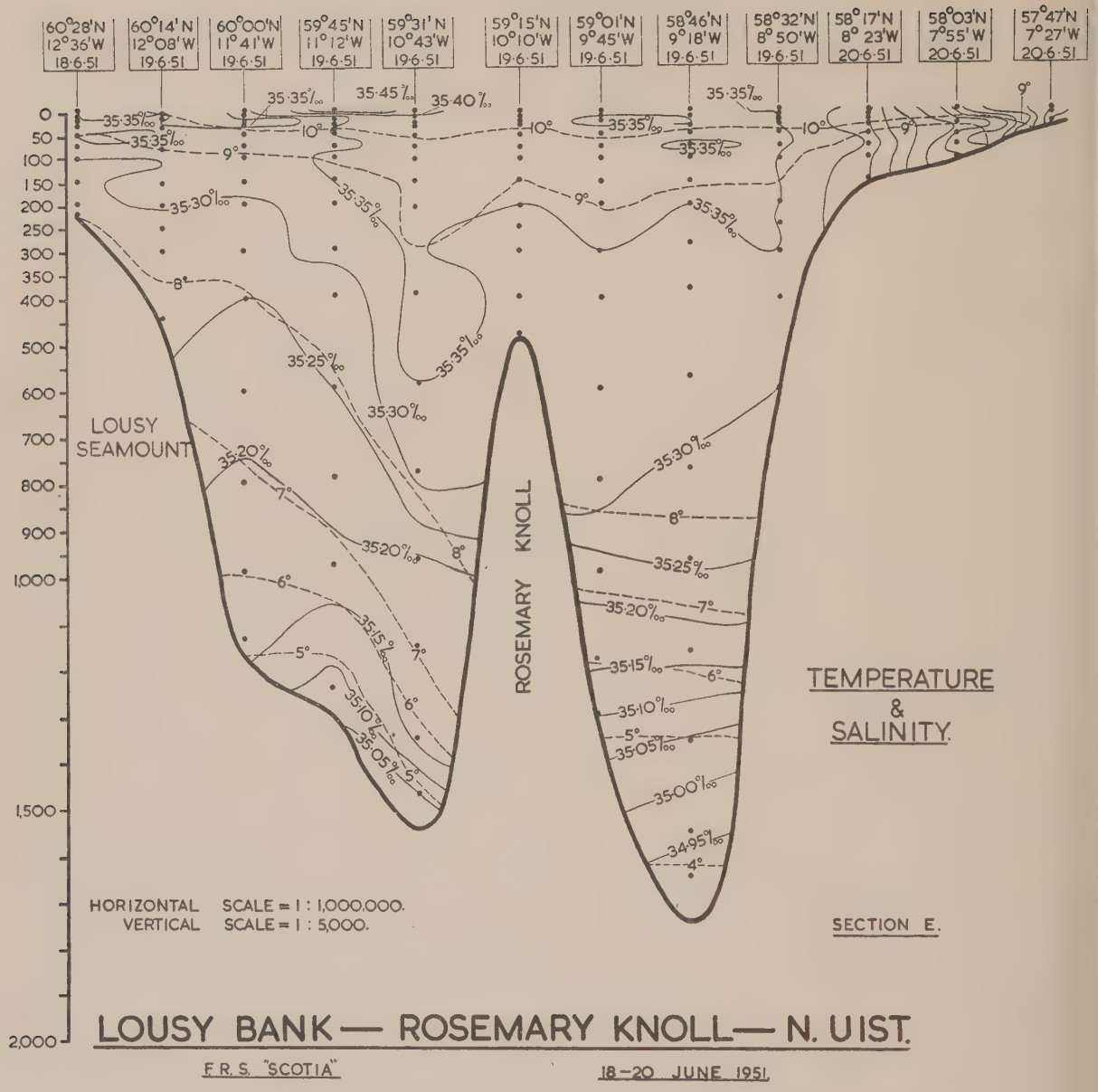
Section D (Figure 13) on the latitude of Rockall itself, traversed a more restricted and somewhat shallower part of the Rockall Channel than either Sections B or C. Since the deepest waters of the two latter sections have just been considered, those of Section D may here first of all be referred to and their most noticeable feature in relation to those further south is the complete absence of such salinity observations in particular as would suggest either Intermediate Arctic or deep Norwegian Sea water. This, of course, raises anew the question of whether such waters on the more southerly sections were in fact moving southward as was supposed, having come into the Rockall Channel from the north. On the foregoing evidence, the more plausible explanation of their occurrence on Sections B and C and not in Section D, and moreover, in apparently greater mass or volume on Section B than on Section C, would seem to be that they broached the Rockall Channel *from the south* and were moving northwards with small and gradually retarding velocity until, very soon after passing through Section C, their further progress was altogether inhibited. So that Fraser's (1955) conception of "a south tending mass of arctic or boreal water" underlying "the whole of the oceanic system to the north and west of Scotland" is probably on occasion at least subject to this modification in respect of the Rockall Channel, this particular northward movement on these occasions stemming from the greater mass of south tending deep water to the west of the Rockall Tablemount.

In regard to temperature, the deepest waters of Section D, it will be observed, did not include the isotherm of 3°C which appears on all three previous section diagrams. The minimum temperature in fact on Section D was only 3·5°C approximately.

The Section still, however, in its upper waters, embraced a western and an eastern high salinity core, both being of lower "standard" than the previous cores insofar as they were bounded by 35·40‰ isohalines and embraced maximum salinities of only 35·44‰ and 35·43‰ respectively. These values are not indicative of Gulf of Gibraltar water, and the fact that the western core broke surface over a distance of about 70 miles, embracing two observation stations which registered the above maximum salinity of the core on the surface in each case, still further discounts the probability of these cores representing Gulf of Gibraltar water which must therefore have become entirely dissipated in the distance between Sections C and D. The eastern core of 35·40‰ plus salinity water lay between 90 and 140 metres over the edge of the Continental Shelf.

The western core contained, on the surface, the maximum temperature of the Section at 13·43°C. Over the remainder of the section temperatures were less than 13°C, and in the uppermost 50-metre layer the fall in temperature was again marked, amounting on this Section to approximately 2·5°C.

Below about 500 metres, Rosemary Knoll almost bisects Section E (Figure 14), and this protuberance from the sea floor, as can be seen from Figure 14, has some effect upon the temperature and salinity distributions, even in the intermediate layers, of the section. The salt-water core of Section E would appear to be that contained within the 35·35‰ isohaline undulating between 200 and 300 metres across the central part of the section, with a projection downwards to 575 metres immediately westward of the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60°14'N 12°08'W 19·6·51
60°00'N 11°41'W 19·6·51
59°45'N 11°12'W 19·6·51
59°31'N 10°43'W 19·6·51
59°15'N 10°10'W 19·6·51
59°01'N 9°45'W 19·6·51
58°46'N 9°18'W 19·6·51
58°32'N 8°50'W 19·6·51
58°17'N 8°23'W 20·6·51
58°03'N 7°55'W 20·6·51
57°47'N 7°27'W 20·6·51
0
50
100
150
200
250
300
350
400
500
600
700
800
900
1,000
1,500
2,000
LOUSY SEAMOUNT
ROSEMARY KNOLL
TEMPERATURE & SALINITY.
HORIZONTAL SCALE = 1 : 1,000,000.
VERTICAL SCALE = 1 : 5,000.
SECTION E.
LOUSY BANK — ROSEMARY KNOLL — N. UIST.
F.R.S. "SCOTIA"
18–20 JUNE 1951.

Fig. 14.

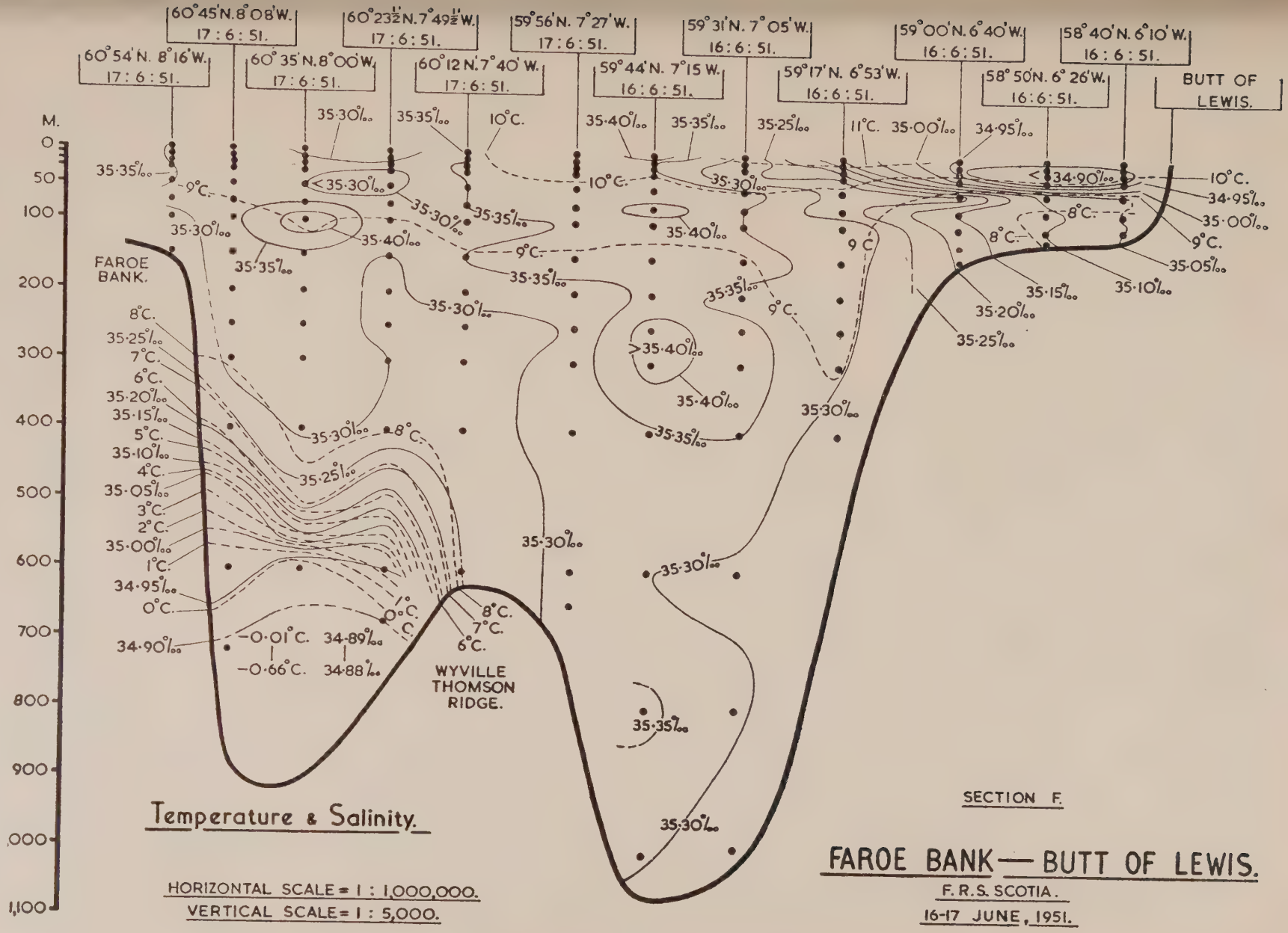
60°54'N. 8°16'W. 17:6:51.
60°45'N. 8°08'W. 17:6:51.
60°35'N. 8°00'W. 17:6:51.
60°23½'N. 7°49½'W. 17:6:51.
60°12N. 7°40'W. 17:6:51.
59°56'N. 7°27'W. 17:6:51.
59°44'N. 7°15'W. 16:6:51.
59°31'N. 7°05'W. 16:6:51.
59°17'N. 6°53'W. 16:6:51.
59°00'N. 6°40'W. 16:6:51.
58°50'N. 6°26'W. 16:6:51.
58°40'N. 6°10'W. 16:6:51.
BUTT OF LEWIS.
M.
0
50
100
200
300
400
500
600
700
800
900
1,000
1,100
FAROE BANK.
WYVILLE THOMSON RIDGE.
Temperature & Salinity.
HORIZONTAL SCALE = 1 : 1,000,000.
VERTICAL SCALE = 1 : 5,000.
SECTION F.
FAROE BANK — BUTT OF LEWIS.
F.R.S. SCOTIA.
16-17 JUNE, 1951.

Fig. 15.

summit of Rosemary Knoll. Besides two subsurface nuclei of *minimum* salinity, 35·34‰—which, of cours may or may not be real—this core contains, on the surface of a very thin superficial laminar layer 35·40‰ plus salinity water, a maximum salinity observation of 35·50‰, indicative by its magnitude Gulf of Gibraltar water. Besides it being most unusual, however, for such an index to occur on the surfac it is recalled here that no indication of Gulf of Gibraltar was recorded on Section D, suggesting its enti dissipation before attaining the latitude of that section. In the circumstances, therefore, the above isolat surface indication of its presence still on Section E, may be regarded either as that of a mere remna of the water-mass which was definitely represented on Section A in two cores of small but appreciab cross-section, and persisted with some cross-sectional restriction and attenuation of its properties throug Sections B and C, or, as deriving immediately from another direction, namely, from the west. As will l seen presently, the latter probability is consistent with certain features on Section F. Apart, howeve from this particular phenomenon, westerly influence on Section E is strongly suggested by the forms the isotherms and isohalines on Figure 14 in the mid and upper waters between Lousy Seamount an Rosemary Knoll.

The sharp thermal declination in the uppermost 50-metre layer which was a characteristic of a four previous sections is scarcely in evidence on Section E, surface temperatures of under 10°C to ju over 11°C falling only about 1°C in 50 metres.

The deep waters on either side of Rosemary Knoll differed relatively little in their characteristic registering temperatures of from about 4°C to 7°C, and salinities from 35‰ to 35·20‰ west of Rosema Knoll and, on the east side, from 34·93‰ likewise to 35·20‰. 34·93‰ is, of course, characteristic bottom Norwegian Sea water, but it is difficult to see how this could have got here even if the temperatu were appropriate to this type of water.

Section F (Figure 15), the last section of this survey, was the standard Scottish Faroe-Shetland Chann threshold hydrographic section between the Butt of Lewis and Faroe Bank, passing over the Wyvil Thomson Ridge. It has already been reported in Tait, 1957, from which Figure 15 is reproduced. Th deep saltwater core—in excess of 35·35‰ salinity—would appear to be a continuation of the simil core of Section E, but whereas the latter apparently included subsurface nuclei of *minimum salin* (35·34‰)—certainly nothing above 35·39‰ salinity save for the thin superficial layer of ostensib residual Gulf of Gibraltar water—the former, i.e. on Section F, included, one above the other, at abo 75 and 250 metres respectively, two *maximum* salinity nuclei of 35·43‰, the water column in whi these occurred being topped by a surface value of 35·42‰. These circumstances suggest the intrusi of these nuclei into the southerly derived current *after this had crossed Section E* and the further eviden of a similar nucleus occurring at 100 metres on Section F over towards Faroe Bank points to its arriv on the section from the west, a surmise which is strengthened by the observation of 35·52‰ salini at 138 metres depth (just above the bottom) on Bill Bailey's Bank on longitude 10°20′W.

The occurrence of the intermediate Arctic type of water (salinity 34·88‰-34·89‰) on Section in the deep part between the Wyville Thomson Ridge and Faroe Bank is to be noted in view of previou references to its occurrence on the more southerly sections B and C but not on Section E.

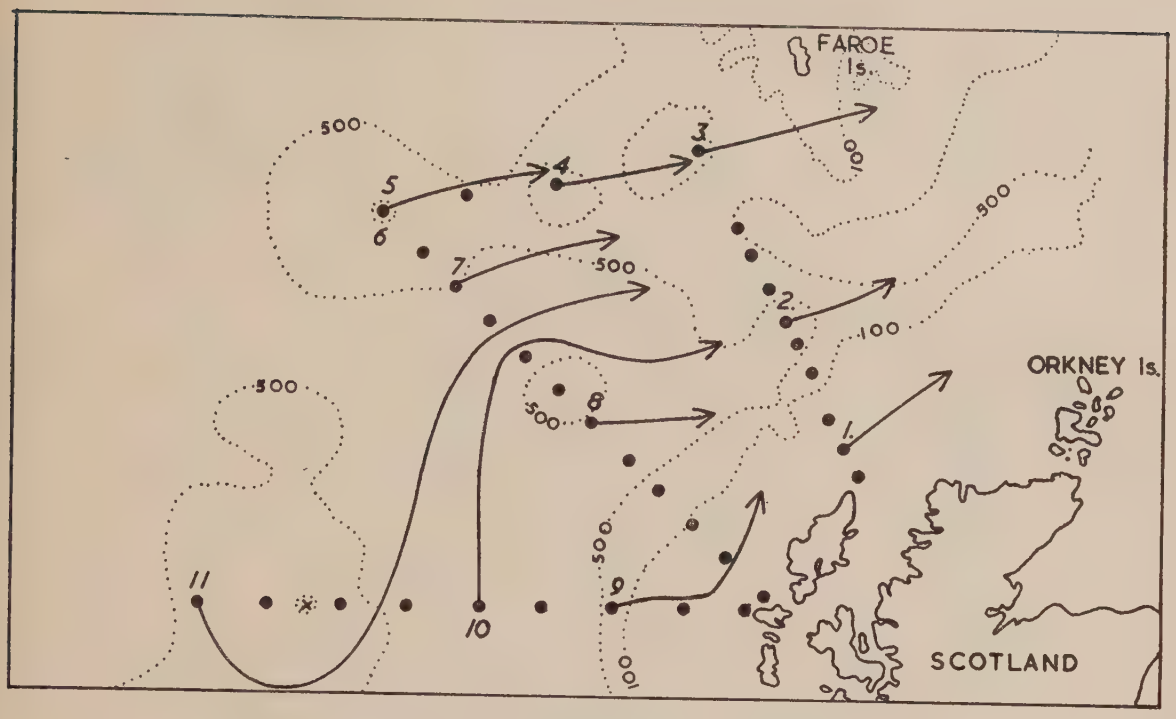

Fig. 16. Initial Tracks of drift-bottles, recoveries nos. 1-11.

Fig. 17. Probable tracks of drift-bottles, recoveries nos. 12-15.

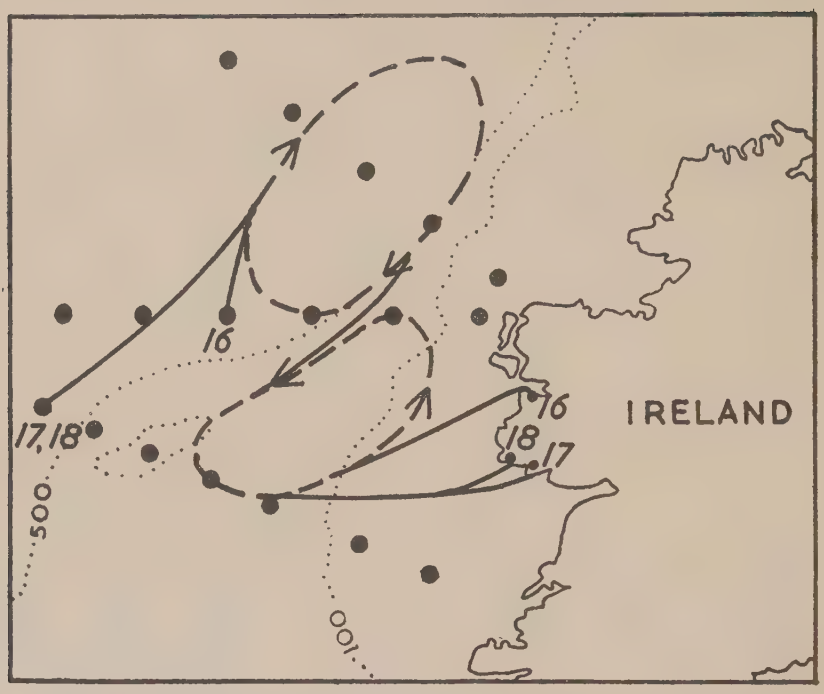

Fig. 18. Probable tracks of drift-bottles, recoveries nos. 16-18.

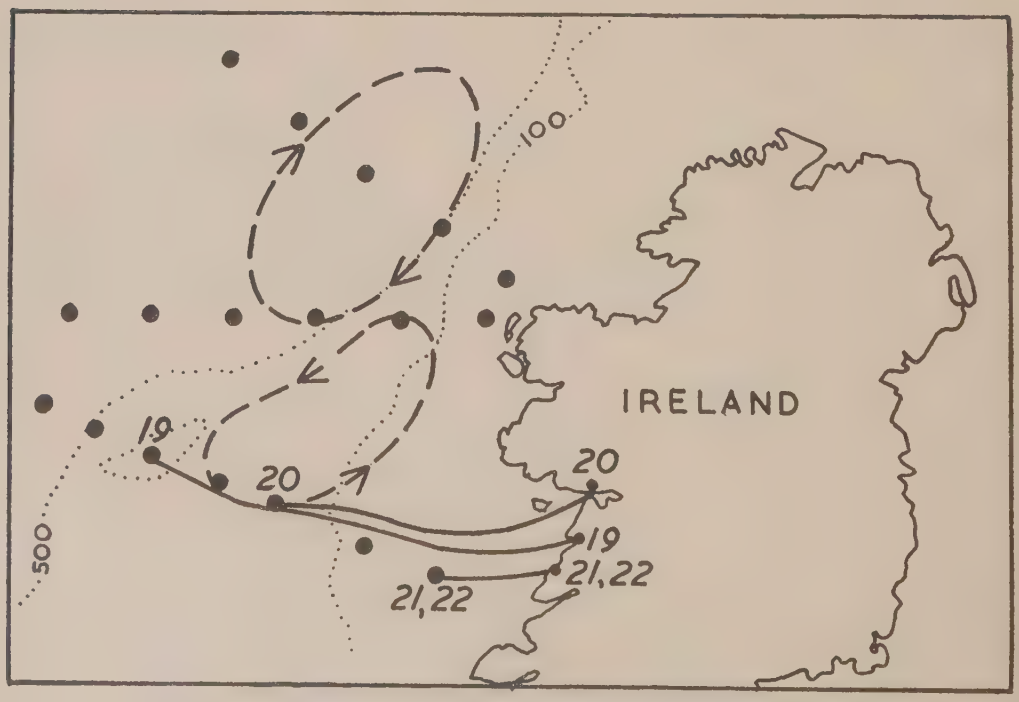

Fig. 19. Probable tracks of drift-bottles, recoveries nos. 19-22.

SURFACE DRIFT-BOTTLE RESULTS

Of 160 drift-bottles liberated by "Scotia," in groups of five (in one instance ten), from the positions marked "D" on Figure 1, 22 recoveries have been recorded. There are listed in Table 1, each with an index number for convenient reference, with its drift-period, that is, the number of days between the dates of release and recovery and necessarily including the period which the bottle may have lain on the shore before discovery.

TABLE 1

Index No.	Release Position	Recovery Position	Drift-Period (days)	Recovery date
1	58°50′N 6°26′W	67°25′N 13°51′E	288	30. 3.52
2	59°44′N 7°15′W	68°36′N 14°20′E	150	14.11.51
3	60°54′N 8°16′W	68°27′N 16°08′E	122	17.10.51
4	60°42′N 10°18′W	67°38′N 12°42′E	143	8.11.51
5	60°28′N 12°36′W	63°17′N 8°05′E	180	15.12.51
6	„ „	65°55′N 12°11′E	625	4. 3.53
7	60°00′N 11°41′W	63°55′N 8°40′E	252	26. 2.52
8	59°01′N 9°45′W	67°10′N 14°20′E	416	8. 8.52
9	57°40′N 9°27′W	63°49′N 8°44′E	251	27. 2.52
10	57°40′N 11°21′W	68°03′N 13°33′E	199	7. 1.52
11	57°40′N 15°11′W	64°49′N 10°34′E	179	26.12.51
12	55°07′N 11°29′W	54°56′N 8°27′W	87	19. 9.51
13	54°28′N 10°06′W	54°35′N 8°27′W	26	20. 7.51
14	„ „	55°01′N 8°30′W	24	18. 7.51
15	54°15′N 12°00′W	54°37′N 8°10′W	52	19. 8.51
16	54°15′N 12°51′W	53°46′N 9°50′W	81	17. 9.51
17	53°41′N 14°44′W	53°24′N 9°55′W	88	25. 9.51
18	„ „	53°25′N 10°05′W	77	14. 9.51
19	53°25′N 13°43′W	52°56′N 9°20′W	60	29. 8.51
20	53°04′N 12°11′W	53°15′N 9°07′W	59	28. 8.51
21	52°40′N 10°40′W	52°44′N 9°32′W	18	19. 7.51
22	„ „	52°46′N 9°30′W	14	15. 7.51

Using the dynamic picture already evolved, Figures 16 to 19 show the probable tracks followed, only initially in some cases, by the 22 bottles concerned.

Bottles numbers 1 to 11 (Figure 16) were found on the coast of Norway between latitudes 63°N and 68° 40′N, and therefore almost certainly passed through the Faroe-Shetland Channel in the early stages of their sea courses. Most of the drift-periods are at least fairly long, pointing to more or less involved courses, due probably to eddy influence and perhaps in some cases to sojourn in the northern North Sea (Tait 1930), as indicated by bottle No. 9 of certain Weather Ships' records cited below. Even the shortest of the six shorter-period recoveries effected between mid-October 1951 and early January 1952, a period of extraordinarily strong current through the Faroe-Shetland Channel according to Tait (Tait 1957) yields, on the assumption of a direct passage occupying 122 days, an average drift-speed of only between 7 and 8 miles per day which is scarcely consistent with the estimate of some 13 to over 14 miles per day derived from dynamic assessment (Tait 1957).

Bottles numbers 12 to 15 (Figure 17) fetched up on the coast of Donegal, Ireland, in from 24 to 87 days. The shortest of these drift periods, relating to bottles set adrift within 35 miles of their stranding places, seem again to indicate involutionary courses. The bottles may have become involved in the more southerly of the two eddies deduced hydrodynamically above, but against this explanation is the circumstance that no other bottle of the same group is recorded as having beached farther south on the Irish coast along with recoveries numbers 16 to 22 which apparently did emerge from this southern eddy before stranding (Figures 18, 19). It seems probable that bottles numbers 16, 17 and 18 circulated first in the more northerly eddy before passing into the southern one, but the latter circulation alone probably accounted for the excessive drift-periods of bottles numbers 19 and 20 as compared with those associated with recoveries 21 and 22.

Fig. 20. Estimated tracks from release positions of 20 drift-bottles liberated from Weather Ships in May, June and July 1951.

WEATHER SHIPS' DRIFT-BOTTLE RESULTS

It is interesting to associate with the above results certain similar records from contemporary Weather Ships' liberations. 325 bottles were liberated in approximately the same region as that surveyed by "Scotia", by the Weather Ships, "Explorer", "Observer", "Watcher" and "Cirrus", during May, June and July 1951. Of these, 20 recoveries have been recorded as listed in Table 2.

TABLE 2

Index No.	Date of Release	Release position		Recovery position		Drift-period days
1	18/5	51°04′N	12°00′W	52°05′N	09°58′W	102
2	19/5	57°10′N	14°00′W	63°56′N	08°55′E	317
3	29/5	57°10′N	14°00′W	66°33′N	12°16½′E	247
4	7/6	55°09′N	10°00′W	58°23′N	05°10′W	79
5	7/6	„	„	55°11′N	07°53½′W	36
6	23/6	52°39′N	19°46′W	c.53°26′N	10°10′W	88
7	28/6	56°26′N	10°00′W	60°30½′N	01°35′W	96
8	29/6	57°08′N	12°00′W	55°10′N	08°05′W	55
9	29/6	„	„	60°33′N	04°51′E	162
10	29/6	57°35′N	14°00′W	64°53′N	10°59′E	183
11	14/7	52°27′N	20°00′W	c.61°03′N	04°50′E	210
12	18/7	59°07′N	19°15′W	60°25′N	01°24′W	361
13	20/7	54°52′N	10°00′W	55°11½′N	06°58′W	23
14	20/7	„	„	55°22½′N	07°24′W	24
15	20/7	53°39′N	14°00′W	c.53°52′N	09°53½′W	62
16	20/7	„	„	c.53°45′N	10°04′W	58
17	20/7	54°17′N	12°00′W	c.66°36′N	12°41′E	240
18	26/7	56°36′N	10°00′W	60°25′N	01°24′W	149
19	27/7	58°12′N	16°00′W	71°01′N	27°22′E	363
20	27/7	„	„	c.68°12′N	13°34′E	204

The release positions and, where possible, the recovery positions, index numbers and estimated tracks of these 20 bottles are shown on Figure 20.

Bottles numbers 2, 3, 9, 10, 11, 17, 19, and 20 were found on the Norwegian coast between latitudes 60°30′N and 71°01′N, having almost certainly, as in the cases of bottles 1-11 of "Scotia's" releases, passed through the Faroe-Shetland Channel. Here again, the somewhat long drift-periods recorded suggest that the bottles did not drift directly to their stranding places.

As will be observed from Figure 20, three recoveries took place in Shetland (Nos. 7, 12 and 18), one (No. 4) in north-west Scotland, and the remainder, eight bottles, on the west and north-west shores of Ireland. Particularly noticeable are the results numbers 8 and 9. Interpreted on the basis of the dynamic picture (Figure 5), it is estimated that bottle number 8 diverged from the north-northeasterly current through the liberation position to return southward and so tc the north coast of Ireland, approximately by way of the liberation positions of bottles 4, 5, 13 and 14, whereas bottle 9 apparently continued via Rosemary Knoll into and through the Faroe-Shetland Channel to the Norwegian coast. The course represented for bottle 17 again also depends upon the surface dynamic topography already deduced.

The courses of bottle numbers 15 and 16 seem to have been influenced by the more southerly of the two eddies deduced as operative off the west coast of Ireland. The drift-periods indicate absorption by and circulation within this eddy for some time.

Recovery number 6 was associated with the two foregoing returns from the point of view of both date and position of recovery, and affords, moreover, an interesting and informative comparison with bottle number 11 liberated within a few miles of number 6. The former ultimately reached the Norwegian coast almost within the limits of the Northern North Sea. Its estimated course initially would seem to imply not only the convergence about the south end of Rockall Tablemount of currents proceeding from the west and south respectively, but also the possibility of some admixture of southerly derived

15°
10°
5°
FAROE Is.
100
500
60°
ORKNEY Is.
SCOTLAND
55°
IRELAND
ENGLAND
WALES
Surface currents
50°

Fig. 21.

waters with those from the west in the north-northeasterly flowing current through the Rockall Channel, a feature which is strongly supported by plankton evidence.

While for lack of contributory evidence a more or less direct route is postulated for bottle number 1, its drift-period rather suggests a course somewhat as indicated by the pecked curve connecting liberation position and stranding place.

The initial course estimated for bottle number 12 found in Shetland is in conformity with its probable relationship to bottles numbers 19 and 20 and to other Shetland recoveries, and conforms also with the foregoing dynamic conception regarding currents approaching Rockall Tablemount.

CONCLUSIONS

The main features of the current system of the uppermost waters at least, as deduced from this cruise, are schematically represented in Figure 21.

It seems reasonable to conclude from this investigation that while, in the main, as was apparently suggested originally by Nansen (1913), the Atlantic Current in the Faroe-Shetland Channel comprises water which derives immediately from the south by way of the channel between Rockall Tablemount and the continental shelf west of Ireland, this is nevertheless mixed with a more or less considerable inflow directly from the N.E. Atlantic Ocean west and north-west of Rockall.

Accepting Helland-Hansen and Nansen's topography (1926 Pl. 62) for 100 decibars over 2000 decibars as approximating to streamlines of flow, it can also be accepted approximately that the surface flow is the same as, or very similar to, that at 100 decibars. The results of the "Scotia" cruise can then be considered as a continuation of Helland-Hansen and Nansen's current sweeping down from the vicinity of latitude 60°N, longitude 20°W, in a south-easterly direction towards Rockall, thereabouts converging with a main current from the direction of south to south-west. This current, according to Helland-Hansen and Nansen's diagrams, would appear ultimately to derive from central North Atlantic regions west of longitude 30°W and below about latitude 50°N, but at least the occasional occurrence of Gulf of Gibraltar water salinities as well as plankton species from the region (Fraser 1955) in the subsequent flow through the Rockall Channel, obviously indicates convergence of this central North Atlantic water with still more southerly derived continental waters progressing northwards from and off the Iberian peninsula. The combined current through the Rockall Channel clearly heads towards and into the Faroe-Shetland Channel.

Another influx into the Faroe-Shetland Channel, which is often indicated in its north-western part by temperature and salinity distributions, by certain plankton species (Fraser 1952) and to some extent by surface drift-bottle results, would appear to emanate more immediately from west of the Channel proper somewhere south of Iceland to about latitude 60°N and joining or flowing alongside the main current from the south as it diverges fairly sharply eastward about Faroe Bank.

These investigations indicate also the existence of a barrier preventing the direct passage of water between Rosemary Knoll and Lewis into the Faroe-Shetland Channel, except perhaps near to the coast of Lewis. Dynamic results strongly support the indications of temperature, salinity, and oxygen distributions in this respect. It is probable that the barrier may be due to irregularities in the bottom topography of the region.

Again, there is good dynamic evidence, well supported by drift-bottle results, to show the existence of two eddy circulations off the west coast of Ireland. One, the main one, circulating clockwise, lies to the north-east of Porcupine Bank and is centred about latitude 55°07′N, longitude 11°29′W. The other, immediately to the south of the first, is an anticlockwise circulation, centred about latitude 53°45′N longitude 11°55′W.

The current arrows on Figure 21, which lie outwith the boundaries of the grid of stations occupied by "Scotia", are based on extrapolation supported by plankton indications and/or drift-bottle evidence. Flow towards the south in the south-west corner of the chart is based upon the dynamics, and in this connection it is interesting to note that in 1950 one of the drift-bottles released by the Weather Ships

in position 51°09′N 16°00′W, was recovered in France from position 49°27′N 01°49½′W., 165 da after it was released. Flow from the south in the region of latitude 54°N longitude 20°W is based up Weather Ships' drift-bottle results, a study of the vertical sections, and to a considerable degree plankton indications. The flow from the north-west towards Rockall again derives from Weather Shi drift-bottle results, as well as from Helland-Hansen and Nansen's dynamic indications from earlier wo

The results of the "Scotia" cruise of June 1951 do not of course necessarily mean that the hydr graphic conditions above described are more or less permanent features of the region; indeed there planktonic evidence (Fraser 1952) of annual variations in these conditions and Lusitanian fauna w unusually well represented in the Faroe-Shetland Channel in only nine of the twenty-eight years examin (Fraser 1954). The question as to the nature of the apparent barrier to water movement between Ros mary Knoll and the Outer Hebrides also remains unanswered.

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